A LARGE MULTI-RINGED STRUCTURE ON EUROPA: A POSSIBLE REMNANT OF AN IMPACT BASIN BURIED BENEATH THE ICE CRUST.
M. Carr[1], F. Chuang[1], M. Belton[2], K. Bender[3], C. Chapman[4], R. Greeley[3], A. McEwen[5], R. Sullivan[3], and the Galileo Imaging Team, [1] USGS, Menlo Park CA, [2] National Optical Astronomy Observatories, Tucson AZ, [3] Arizona State University, Tempe AZ, [4] Southwest Research Institute, Boulder CO, [5] University of Arizona, Tucson AZ.

Images taken early in the orbital phase of the Galileo mission reveal the presence of a large, indistinct, circular structure on the anti-Jovian hemisphere of Europa. The multi-ringed nature of the feature is difficult to discern in Mercator projections; it is best seen in stereographic projections centered on the middle of the structure at 19S, 203W. The rings are defined by dark triple bands and the boundaries between mottled plains and smooth plains. The most prominent arcs are, to the north, part of Belus Linea at 1,120 km from the center and Minos Linea at 1,750 km, to the southeast, Adonis Linea at 1,860 km and Serpadon Linea at 2,650 km, and to the east, boundaries between smooth plains and mottled plains at 1,300 km, 1,800 km and 2,200 km. Numerous other dark lineae form arcs around the same center. At the center of the structure is an area with a complicated pattern of dark wedges and arcuate dark bands, interpreted as a “pull-apart” zone (1). Arcs delineating the multi-ring structure constitute only a fraction of all the arcuate features on the anti-Jovian hemisphere. Many others cross the structure and do not appear to be related to it.

The fractures and the surface they cut appear to be mostly young. Within the area photographed during the first two orbits during the Galileo mission are a 30 km diameter crater and a 50-km diameter crater. This observation coupled with estimates of the Europa cratering rates (2) suggests a crater retention age for the surface of the order of 10^7 years. Craters older than this have either been buried or so modified by isostatic adjustment and/or tectonic disruption that they are no longer recognizable. Rays from the 50 km diameter crater are superimposed on many of the lineae. High resolution views of Europa taken on Galileo’s C3 orbit show that at least some parts of the surface are very sparsely cratered. These surfaces could be significantly younger than 10^7 years, and the fractures cutting the surface must be younger still. Whatever processes have caused the fractures, they are likely to be continuing today.

The lineaments on Europa have mostly been interpreted as fractures (3,4,5). The cause of the fracturing has been variously ascribed to global expansion as a result of phase changes or dehydration of the interior (6), to global contraction as a result of global cooling (7), and to tidal stresses caused by Europa’s orbital eccentricity (7,8). For a spherically symmetrical Europa in synchronous rotation, the pattern of fracturing due to tidal stresses and orbital recession should be symmetrical about the anti-Jovian longitude, and the Jovian and anti-Jovian hemispheres should have similar fracture patterns (7). However, Europa may not be rotating synchronously. Because of the tides and the eccentric orbit, torques averaged over one orbit are non-zero (9, 10). This could cause a slight difference in the orbital and rotational periods and slow asynchronous rotation. The entire body could rotate asynchronously, or the ice crust could slowly rotate over a silicate interior that is in synchronous rotation. In both these cases the stress fields caused by the tides and orbital recession will move slowly across the surface (8, 11), and over time, all longitudes should experience the same stress pattern.

Neither the proposed models (expansion, contraction, orbital recession coupled with synchronous or asynchronous rotation), nor combinations thereof, fully explain the observed fracture patterns. Lack of symmetry about the Jovian and anti-Jovian points and lack of similarity between the Jovian and anti-Jovian hemispheres appear to rule out expansion and contraction coupled with synchronous rotation as the sole causes of the fracture pattern. A better fit between the observed and predicted patterns is achieved, if we assume that we are seeing the results of asynchronous rotation In this case the maximum tensile stresses occur 45^0 ahead of the moving tidal axis, that is at 225W in the anti-Jovian hemisphere, and tensile fractures forming today should form an elliptical pattern centered on the equator at 225W. Many of the fractures do indeed roughly correspond to this pattern, so that we may be seeing the most recent fracturing as a result of asynchronous rotation. We may not be seeing the effects of older tidal fracturing because the dark markings, by means of which the fracture are identified, fade with time, as is indicated by intersection relations (1). A better fit is obtained if stress trajectories for asynchronous rotation are displaced eastward by 25^0, as if the fractures preserved a record of asynchronous rotation from a previous epoch (12), but this implies that the fractures formed by a mechanism that has turned off, which is contrary to the seemingly young age of much of the surface, as discussed above..

None of the proposed mechanisms explain why some of the fractures and some of the boundaries between different surface units should outline a circular structure offset from the equator at 19S, 203W. One possibility is that the silicate subcrust that underlies the ice crust is not homogeneous and does not form a smooth surface but instead retains a record of cratering events from very early in the history of the body. Inhomogeneities in the silicate subcrust and the topography of the silicate surface could then have influenced the way that the icy crust responds to the tidal stresses. In particular we suggest that the circular structure centered at 19S, 203W indicates the presence of an ancient impact basin in the silicate subcrust centered at that location. The basin may be located close to the anti-Jovian point because the basin results in a center of mass offset, thereby locking at least the silicate interior in its present orientation with respect to Jupiter.

The presence of an ancient impact scar could influence the way the ice crust deforms in at least two different ways. In the first case the ice crust is mechanically coupled to the silicate subcrust. Tidal stresses in both the ice crust and silicate subcrust would tend to be relieved along previously formed dislocations, and dislocations in the silicate subcrust would propagate upward into the ice crust. If rotation is asynchronous, as appears more likely from the universal fracturing of the surface, then fractures asociated with the basin would be reactivated periodically in the asynchronous cycle when the stresses were appropriately oriented for the fractures. The resulting pattern at the surface would be a melding of both the ancient fracture patterns and the patterns predicted by present-day tidal stresses, which is roughly what we see.

In the second case, the ice crust is decoupled from the silicate interior by a melt zone or "ocean".(13). This would cause most of the tidal stresses to be relieved within the ice crust, and would prevent ancient fractures from propagating into the ice. However, any topography on the silicate subcrust would influence the way that the ice crust deformed. In this case the ice crust could rotate asynchronously with respect to both Jupiter and the silicate interior. The fractures that are observed today should reflect only those fractures that formed in the most recent epoch of deformation. According to this interpretation the fracture pattern is the result of current, or recent, tidal stresses as modified by flexure of the crust and interaction of the low viscosity "ocean" layer with the topography of an ancient multiringed basin in the silicate subcrust.

Thus there are several combinations of configurations and causes that could be invoked to explain the fracture pattern: synchronous rotation with or without an ocean, asynchronous rotation of the whole body, with or without an ocean, and asynchronous rotation of an icy crust separated by an ocean from a synchronously rotating interior. We cannot confidently discriminate between the various possibilities, but the pattern of fractures appears to favor asynchronous rotation as does the pervasive fracturing of the entire crust. With synchronous rotation a similar stress pattern is repetitively applied over long periods of geologic time, and we would expect constant re-activation of the same fractures. This is not what is observed. The most recent images of Europa are more consistent with the continual formation of new fractures until the entire surface is saturated with fractures and no piece is left unfractured. This is more what is expected from asynchronous rotation. But is the entire body rotating asynchronously, or just the icy crust? If indeed the circular structure is a reflection of an impact basin on the silicate sub-crust, then its location close to the anti-Jovian point gives some support to the supposition that the silicate interior is tidally locked. The "pull-apart" zones are an indication of some low viscosity zone below the rigid crust. Our preferred cause for the fracture pattern is, therefore, asynchronous rotation and flexing of a decoupled ice crust over a silicate subcrust that retains on it some topographic record of the early cratering history.

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